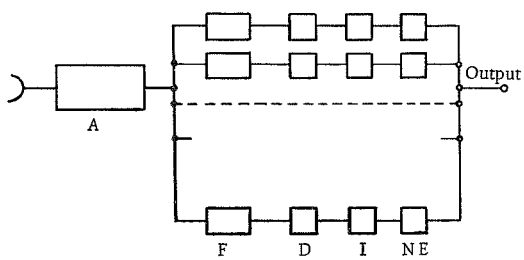
RADIO COMMUNICATION WITH EXTRATERRESTRIAL CIVLIZATIONS

V. A. KOTEL'NIKOV

Institute of Radio Engineering and Electronics
USSR Academy of Sciences

The aim of this paper is to consider the possibilities of communication with extraterrestrial civilizations (whose technology is an outgrowth of scientific principles that are already established on the Earth and which lead the Earth civilization by a few decades. The Earth technology is assumed on the present-day level. Although some civilizations are probably more advanced than we are by thousands or even millions of years, our restricted approach is apparently not unreasonable. This paper does not pretend to completeness: it only discusses some particular examples, which are not meant as illustrations of optimal cases.

Let us consider the transmission of signals in the form of long monochromatic trains of pulses. This technique is no less noiseproof than other methods of transmission, and yet it is simpler to achieve; therefore it will probably be adopted in the beginning by young civilizations for purposes of interstellar communication. The signal frequency is of course not known in advance, and it may change when information is being transmitted. In this case, the optimal receiver will have a circuitry like that block-diagrammed in the figure.



Here A is the amplifier, which may include a frequency changer; F filters with a band Δf overlapping the entire frequency range; D detectors; I integrators which recover the energy passing through the filter during the integration time τ; NE suitable nonlinear elements whose outputs are added. A signal is registered when the output of this receiver exceeds a certain value.

For simplicity, without sacrificing much of the noiseproof properties of the receiver, the nonlinear elements can be replaced with threshold

devices which produce an output signal only if the oscillatory energy passing through the filter in the time τ has exceeded a certain threshold value. It is this particular receiver scheme that is considered in what follows.

Let the transmitting and the receiving antennas with effective surfaces S_1 and S_2 be pointed at one another. The maximum reception range is then given by

$$R = \sqrt{\frac{PS_1S_2\tau}{\lambda^2 k T_n \Psi}}, \qquad (A)$$

where P is the transmitter power, λ the wavelength, $k = 1.38 \cdot 10^{-23}$ J/deg, T_n receiver noise temperature; Ψ is a function of Δf, the number of filters n, and threshold setting, which depends on the probability of false response p_{fr} and the permissible probability of signal loss by the receiver, p_{sl}. When considered as a function of Δf, Ψ has a minimum for $\Delta f \cong 1/\tau$. For p_{fr} and p_{sl} less than 10^{-2}, it is given by

$$\Psi_m \cong \left(\sqrt{\ln\frac{n}{p_{fr}} - 2} + \sqrt{\ln\frac{1}{p_{sl}} - 2}\right)^2.$$

In some cases, when τ is large, Δf cannot be made equal to $1/\tau$, since due to the intrinsic frequency drift the signal will miss the narrow passband of the filter. With $\Delta f \gg 1/\tau$, we have

$$\Psi \cong \sqrt{2\Psi_m \tau \Delta f}.$$

It is undesirable to have $\Delta f < 1/\tau$, since this will complicate the design and increase Ψ, i.e., reduce R.

We now consider a particular example. Let the transmitter power commanded by an extraterrestrial civilization be $P = 10^9$ watt (1% of the electric power requirements of the USA). The effective surface of the transmitting antenna is

$$S_1 = 10^5 \text{ m}^2.$$

and the effective surface of our receiving antenna is

$$S_2 = 10^4 \text{ m}^2.$$

Set noise

$$T_n = 30°.$$

Receiving antennas with these parameters can be built without much difficulty.

Transmission wavelength

$$\lambda = 0.1 \text{ m}.$$

For a frequency drift of 10^{-10} (which is readily attainable at present), we obtain for the filter passband

$$\Delta f = 0.3 \text{ c/s}.$$

With this passband we may take $\tau \gg \Delta f$. Putting $\tau = 1800$ sec, $p_{fr} = p_{sl} = 10^{-5}$ and $n = 10^9$, we find

$$\Psi = 280.$$

From relation (A) we then have

$$R = 1.28 \cdot 10^{21} \text{ m}$$

or 128,000 light years, which is more than the diameter of the Galaxy.

If information is sent through this line, and the signal frequency is changed from transmission to transmission, the information rate is

$$\frac{\lg_2 n}{\tau} = \frac{\lg_2 10^9}{1800} = 1/60 \text{ bits per sec.}$$

The information rate rapidly increases as τ decreases. If we put $\tau = \Delta f^{-1} = 3.3$ sec, and $p_{fr} = p_{sl} = 10^{-5}$, $n = 10^9$ as before, we find $\Psi = 73$ and $R = 10^{20}$ m, or 10,000 light years. The corresponding information rate is

$$\frac{\lg_2 n}{\tau} = \frac{\lg_2 10^9}{3.3} = 9 \text{ bits per sec.}$$

For distances of 100 light years, τ can be reduced by four orders of magnitude, and the information rate will approximately increase to the same extent.

The receiver being considered is provided with fairly narrow-band filters. The transmitter and the receiver both accelerate and decelerate due to the motion of the home planets in space, and this obviously changes the frequency of the signal. These frequency changes must be compensated on location, since otherwise the signal may miss the filter's narrow pass-band. The compensation can be readily introduced since the acceleration of planetary motion is known at each point.

The very large number of separate channels in the receiver (see figure) can be apparently replaced with a simpler device performing the same function.

How are we going to find a star with a powerful transmitter located on one of its planets?

Suppose that the transmitting civilization has built a transmitter with the parameters from the previous example, i.e., $P = 10^9$ W, $S_1 = 10^5$ m^2, $\lambda = 0.1$ m. The antenna is pointed alternatively at different stars or is allowed to scan the entire celestial sphere, drifting across a single star in, say, $\tau = 3$ sec. For large τ, the problem is even simpler.

The antenna beam fills a solid angle $\frac{\lambda^2}{S_1}$, and it therefore scans the entire celestial sphere in the time

$$\tau_r = \tau \frac{4\pi S_1}{\lambda^2}.$$

For the above numerical parameters, we find $\tau_r = 3.8 \cdot 10^8$ sec or 12 years.

A considerably shorter time is obtained if the antenna is pointed at a certain star and then rapidly switched to another star, etc. The scanning time for all the 10^7 stars within the radius of 1000 light years is

$$\tau_r = 3 \cdot 10^7 \text{ sec, or 1 year.}$$

If we assume that a preliminary selection of the most "promising" stars reduces the population to 1% of the total ten millions, the scanning time drops to $\tau_r = 3 \cdot 10^5$ sec, or some four days. The scanning time decreases proportionately for stellar populations within spheres of smaller radii. The technique of rapid antenna switching from one star to another thus reduces the scanning time to a reasonable level.

Let the receiving system be an array of beamed antennas covering the entire celestial sphere. In this case, a transmitter with the above parameters can be detected at a distance of 1000 light years if the receiving antenna surface, according to equation (A), is $S_2 = 100\,\text{m}^2$. It is assumed that the receiver functions as indicated in the figure and that $\Delta f = \tau^{-1}$, $T_n = 30°$. Seeing that the beam of this antenna occupies a solid angle λ^2/S_2, we find that

$$m_2 = \frac{4\pi S_2}{\lambda^2} = 1.2 \cdot 10^5 \text{ beams}$$

are required to cover the entire celestial sphere.

In this arrangement, the antenna is not expected to track the star. Each antenna may therefore have as many as ten beams. The number of individual antennas may therefore be substantially less than m_2. The number of receiving channels, however, must be exactly m_2, and each receiving channel should be equipped with filters overlapping the entire relevant frequency band.

If we assume that the transmitting civilization is sufficiently advanced and its astronomers can actually select the 1% of stars which in principle may support Earth-type civilizations, the scanning of all the selected stars within a sphere of 1000 light years radius will take about four days.

The entire celestial sphere need not be scanned at one time: different areas of the sky, say, those having different declinations, can be scanned at different times. Thus, if the sky is divided into 10 areas, the survey of each area can be completed in, say, one month (the signal, if any, will be detected 7 times during this period), and the entire celestial sphere will be scanned in approximately one year. The number of receiving channels and antennas can be further reduced by one order of magnitude.

The above receiving network, though by no means cheap or easy to build, can be erected on Earth. This system will detect extraterrestrial civilizations which have transmitters with the above parameters and are located within the radius of 1000 light years from the Earth. Since there are nearly 10^7 stars within this sphere, the search will be successful if at least one of the ten million stars has a transmitter of the required kind.

If the distance scale is reduced, the search becomes progressively simpler.

The table below lists some data for spheres with radius of 2000, 1000, 500, and 200 light years with 10^8, 10^7, 10^6, and 10^5 stars, respectively. The data of the table have been derived along the lines indicated above. Column 7 gives the number of areas to be scanned separately if the survey of the entire celestial sphere is to be completed in one year. The scanning time for each area was assumed approximately 10 times greater than the figure given in column 4.

We see from the table that if there is a single Earth-type civilization in 10^8 stars, its detection at the present stage of our technological development is nearly impossible; if there is a single civilization in 10^7 stars, it can be detected with some effort; if there is one civilization in 10^6 stars, its detection by the available means is quite probable.

Radius, light years	Number of stars	Time to scan all the stars	Time to scan 1% of the stars	Receiving antenna surface, m^2	Number of receiving channels to cover the entire sky	Number of survey areas	Number of receiving channels with survey areas
2000	10^8	10 years	36 days	400 m^2	480,000	1	480,000
1000	10^7	1 year	4 days	100 m^2	120,000	10	12,000
500	10^6	36 days	9 hrs	25 m^2	30,000	100	300
200	10^5	4 days	1 hr	4 m^2	4,800	1000	5

If the extraterrestrial civilization commands more powerful resources, we can of course detect it from considerably greater distances.

Once the existence of a civilization has been established, a large antenna should be pointed in the corresponding direction, since besides the powerful call signals intended for detection by other civilizations, it probably transmits information, meaningful messages that can be picked up with high-efficiency antennas only. To establish a bilateral communication, we should send a radio message to the discovered civilization. Our signal will be picked up without any difficulty, since our transmitter can be pointed precisely in the direction of the extraterrestrial civilization that we have previously discovered. After this preliminary exchange of messages, the antennas of the two civilizations will be pointed at one another and a more effective exchange of information will be established.

In conclusion let us consider the possibility of detecting a civilization even though it does not transmit special "detection" signals. The power of the radio transmitters used for internal purposes by these civilizations is probably of the order of tens of kilowatts, and the antennas in common use have a directive gain $g_1 = \frac{4\pi S_1}{\lambda^2}$ (the probability of picking up narrower antenna beams is too small). The receiver passband, as before, is 0.3 c/s. A narrower passband is inadvisable, since the Doppler frequency shift will not be compensated on the transmitting side. For the same reason we take $\tau = 3$ sec, $P = 10^5$ watt, $\frac{S_1}{\lambda} = 10$, $S_2 = 10^5$, $\Psi = 70$, $T_n = 30$. From equation (A),

we find

$$R = 3 \cdot 10^{15}\,\text{m}, \text{ or } 0.3 \text{ light years.}$$

We see that even the civilizations occupying the nearest stars cannot be detected unless they send special signals or radiate (for some obscure reason) exceptionally high power.

CONCLUSIONS

If a civilization does not send special "detection" signals, it apparently cannot be detected even by its nearest stellar neighbors.

If a civilization somewhat more advanced than we (approximately by a few decades) sends special radio signals, we can detect these signals from distances of 500—1000 light years.

Once civilizations have detected one another, they can establish radio communication on the galactic scale.